STUDY OF A SELENIUM CELL

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Study of a selenium cell

STUDY OF A SELENIUM CELL

A THESIS

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INTRODUCTION

Selenium cells have been studied with their ultimate utilization in photometry in view,but little or nothing has been done to perfect them for use for the automatic operation of circuit closing and circuit opening relays,in ordinary lighting circuits.

The idea of making use of the sensitivity of selenium cells to illumination for the operation of relays was suggested to the author by Professor J. E. Snow. It opened up tremendous possibilities for research work and was instantly accepted as a suitable thesis subject.

An exhaustive review of the published literature on the subject of selenium cells proved that the cells,at least in their present form, were not suited directly for the purpose in view. Convinced of this, the author decided to confine himself,for the present,to a study of the characteristics of the cells,more particularly,the

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illumination-current relationship;and leave for future research,the construction and adaptation of a cell for the practical,object in view.A selenium cell was fortunately available in the Physics Department of the Institute.

At different stages of the work,the author freely consulted members of the faculty, particularly Professors Freeman,Wilcox,Doubt,and Marsh, to whom he is greatly indebted.

Valuable aid in the laboratory work was given by Mr.A.Falk,of the Instruemnt Room,whose help and assistance were of material value in making this report possible.

R.A.N.

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Review of the Subject.

Forty three years ago the discovery was made that the resistance of selenium diminishes under the action of light. In the investigations that have followed,many other interesting characteristics have been brought out. It is customary to specify the "sensitiveness" of selenium by stating the ratio in which its resistance is reduced by a given illumination. Selenium cells, properly so called, are electrolytic cells in which the illuminated selenium forms one of the electrodes and generates an e.m.f. Selenium cells in which the action due to light is a change in the resistance of the selenium are more properly termed selenium bridges.

Ever since the discovery of the sensitiveness of the electrical resistance of metallic selenium to alteration in illumination attention has been given to the problem of finding an explantaion of the phenomena. In late years,two views have been

expressed regarding this. Quoting Prof. A. H. Pfund:"Although by no means definitely proved, it seems very probable that the changes in resistance upon exposure to light are due to the selenium itself and to selenides,which are present as impurities. Upon this view,it is considered that light, in falling upon selenium and in being absorbed, sets up resonance within the atom, and this, in turn, gives rise to an expulsion of electrons- thus increasing the number of electrons availablo for carrying the current, and hence,increasing the conductivity."

This view has found favor with some investigators, particularly with Ries,to whom a great amount of valuable work is due. It deserves attention for various reasons: first,the ultimate explanation found must be in terms of the electron theory,if that theory is to remain a permanent part of our physical science. Again, the idea of resonance is a very plausible one

to explain an increase of conductivity.

The second theory may be construed as quite in harmony with the first. Marc and others have obtained evidence that there exisits at least two forms of metallic selenium of widely different electrical resistivity;and it is assumed that illumination brings about a transformation from the less to the more conducting of the two.

Prof. F. C. Brown has advanced a three form theory,A, B, and C, but this has found little favor with scientists.

Selenium is difficult to investigate in that so many agencies alter its conductivity,each to a greater or lessor extent,and it is not always easy to eliminate all except the one under investigation. For example, in studying light action there is a certain heating effect and also a change in the pressure on the selenium. The change in pressure may be due to change in volume in the selenium between the seim-fixed electrodes, as a

result of the light action and the temperature action. The magnitude of the disturbing effects are probably not larger than the observational errors and are hence disregarded. The percentage change of resistance with one atmosphere change of pressure lies between .05 and .30 and hence obviously negligible for all practical purposes.

The general tendency of the cells is for an increase in conductivity, and a consequent decrease of resistance to result from an increase in temperature. A rise in temperature lowers the light sensitiveness of the selenium cell. This light sensitiveness is a function of the resistance of the given cell whether that resistance is conditioned by temperature, pressure, or light. The observations of Ries and others also indicate a slight dependence of the resistance upon humidity.

In late years, the study of selenium cells has

tended toward the proving of a linear relationship between illumination and current.

Photo-electric current is a function of voltage,of electrode distance, of pressure, and of illumination. The effects of pressure variations, electrode distance and voltage, were studied by Stoletow, Varley, and others. All of these studies revealed a complicated relationship between the current and the variables in question.

Richtmyer, using an ordinary cell, found a strictly linear relation between illumination and current, over a range of .01 to 600 foot-candles. Elster and Geitel found this relationship true over even a greater range than Richtmyer investigated. In the photo-electric alkalai cell there are two electrodes, separated by air to which a suitable difference of potential is applied. Then if the negative electrode is exposed to strong light, electrons are emitted, and as a result, a small but measurable current

will flow. These cells are pratcically free from inertia, and the current is, within wide limits, proportional to the intensity of illumination.

Five methods of measuring photo-electric current are found in the literature: (1) by the rate of drift of an electrometer needle; (2) by the ballistic method; (3) by measuring the potential across the terminals of a high resistance in series with the cell; (4) by balancing the photo-electric current with a current variable in a known manner; (5) by the deflection of a sensitive galvanometer. The last method was used in the present work.

The cells vary slightly in sensitiveness in a space of months or years, but these variations are so slight as to be negligible. The dark currents arising in the cell are only of the order of 10^{-13} to 10^{-16} amperes.

Experimental Results.

(a) Description of Apparatus.

The selenium cell, shown in Fig.1, used in this work was the Alder Selenium Cell Standard Type "R" manufactured by the Braun Corporation of Los Angeles Calif. The working surface is a circular aperture ½ inch in diameter. The selenium is spread in a coating of approximately 1/10,000 of an inch, on German silver which has been previously heat-treated. The whole cell is baked for a number of hours, to exclude all moisture, before being permanently sealed. Sealing is done while hot. All open spaces within the cell are filled with Canada balsam, baked hard. Each cell is fitted with clips to hold absorption cells for spectroscopic work.

The Macbeth Illuminometer shown in Fig.6 was used to measure the illumination intensities. It consists of three main parts and various accessories. The three main parts are the illuminometer, the controller, and the reference standard. A Lummer Brodhum cube is mounted in the rectangular head of

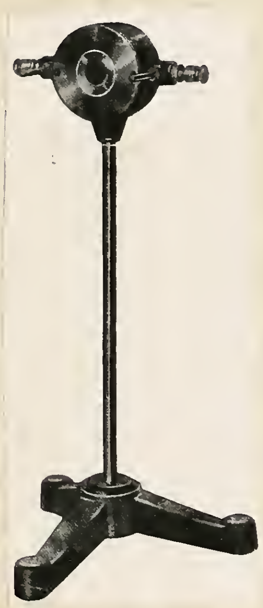

Fig.1. The Selenium Cell

the illuminometer. The photometric field is viewed through the telescope. The aperture opposite the telescope is aimed or pointed toward the test plate. On one side of the rod to which the lamp carriage is attached is engraved the direct reading scale, calibrated from one to twenty five foot candles.

The controller comprises the battery for operating the lamps, a Weston milli-ammeter,two close regulating rheostats, and a double throw switch.

The elimination of the personal factor which is always present when using illuminometers standardized by others is of the greatest importance. In the Macbeth Illuminometer each operator standardizes by means of the reference standard against an exact known illumination intensity,and thus compensates for the personal difference of various photometric observers.

The accessory apparatus consists of a test plate, tripod and horn.

The deflection galvanometer used was of the D'Arsonval type,dead beat, manufactured by the Chicago Laboratory and Scale Co. Machine waste was placed under the casing to minimize the vibrations of the suspension due to shock.

The Standard Laboratory Set used by the Electrical Department was used to make the dark resistance measurements. The auxiliary apparatus consisted of a potential rheostat, voltmeter, battery and galvanometer key, portable D'Arsonval galvanometer and standard resistance boxes.

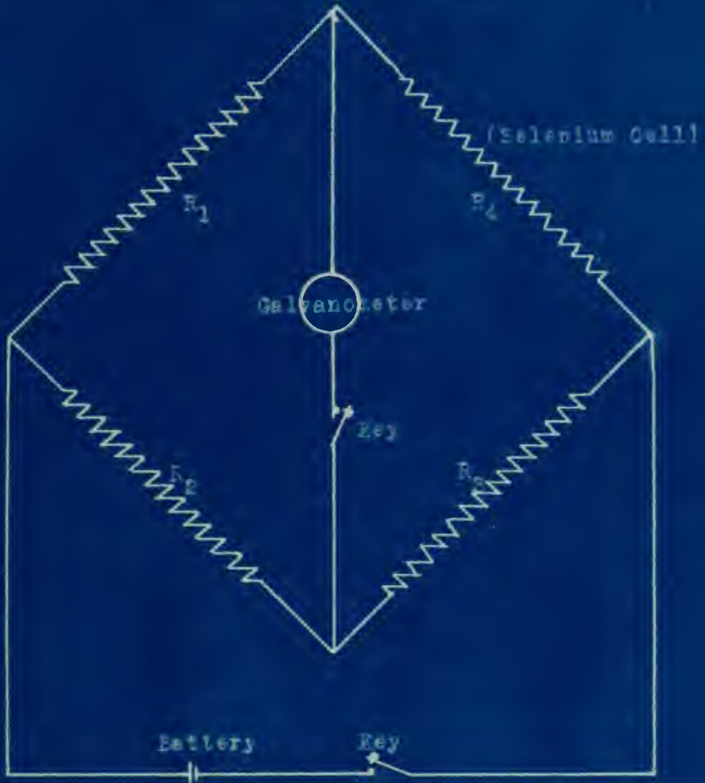
(Selenium Cell)
R_1
R_4
Galvanometer
Key
R_2
R_3
Battery
Key

Fig. 2. Theoretical Diagram of Connections—Standard Laboratory Set and Wheatstone Bridge.

(b) Method Of Procedure.

As the cell had been kept in the dark for several months, its dark resistance was first determined. A battery key was used, first closing the battery and then the galvanometer circuit, thus eliminating the effects of inductance and capacity. A careful Wheatstone Bridge balance gave the dark resistance as 3,000,000 ohms. The measurement was then carefully checked with the Standard Laboratory Set and a result of 2,999,000 ohms was obtained. This was considered sufficiently accurate.

The next step was the calibration of the D'Arsonval galvanometer. The apparatus was connected as shown in Fig.3. Resistance boxes replaced the cell in the scheme. The deflections of the needle were read by the usual method of telescope at meter distance and reflected beam of light. Maximum deflection of the needle was obtained at four volts and 500,000 ohms. A voltage-deflection curve was first obtained with the resistance constant at 1,600,000 ohms. (Shown in Fig. 4.)

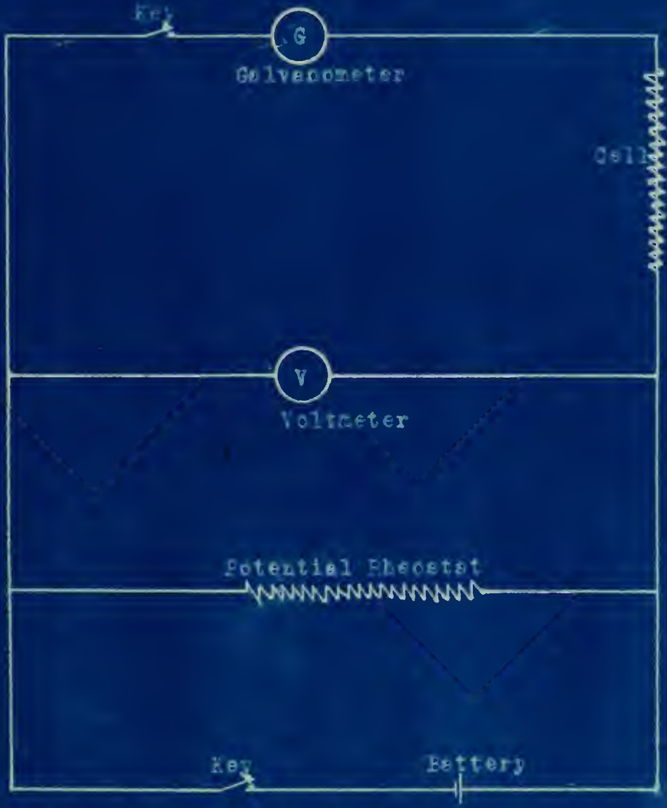
Key
G
Galvanometer
Cell
V
Voltmeter
Potential Rheostat
Key
Battery

Fig.2. Diagram of Connections-
Illumination-Current Relationship.

Then a resistance deflection curve was taken with the voltage constant at four volts. If D and R represent, respectively, the deflection and the resistance causing that deflection, then the resistance R' causing another deflection D' is

$$R' : R :: D : D'$$

or,

$$R' = R \times \frac{D}{D'}$$

Since the current-deflection relationship is the same as the resistance-deflection, it was thought best to use the resistance notation all through the work, as the quantities involved were much larger numerically. The results were plotted giving curves as shown in Figs. 4 and 5.

The cell was then substituted for the resistance boxes and a check made on the dark resistance. A deflection of 6.76 cm. gave a resistance of 3,000,000 ohms which checked the previous work done. The cell was placed beside the test plate and the illumination was measured. It was broad daylight

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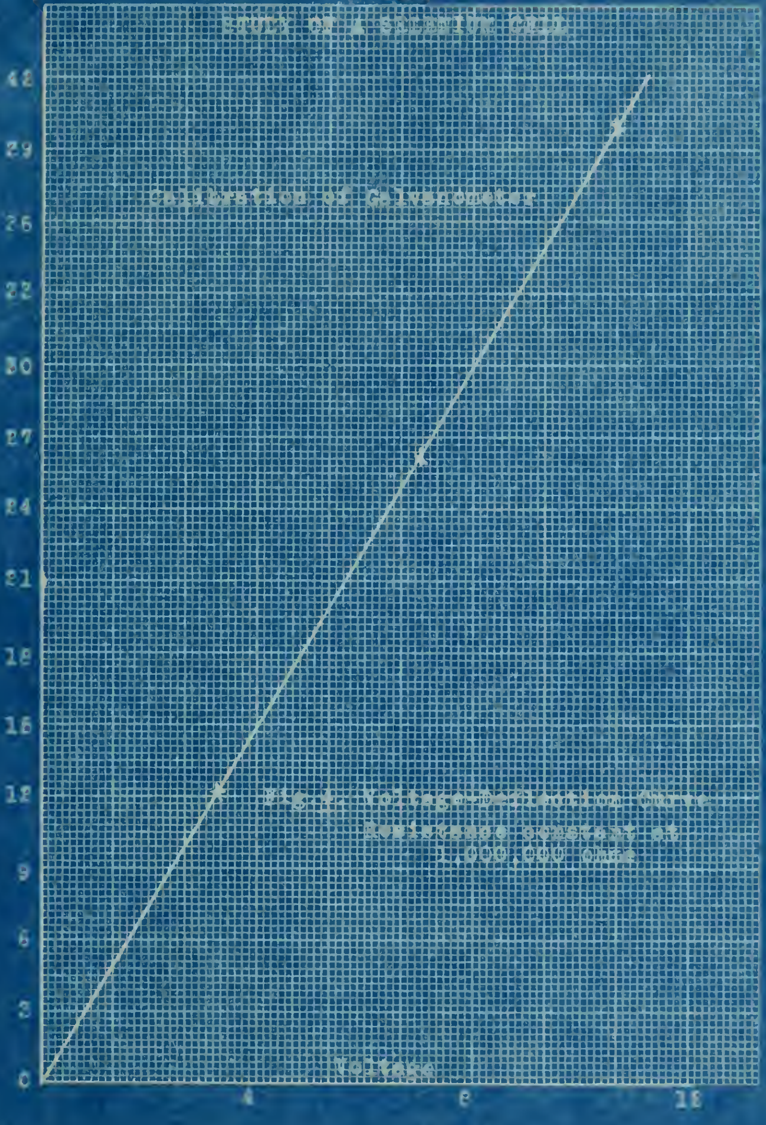

Calibration of Galvanometer

Fig 4. Voltage-Deflection Curve
Resistance constant at
1,000,000 ohms

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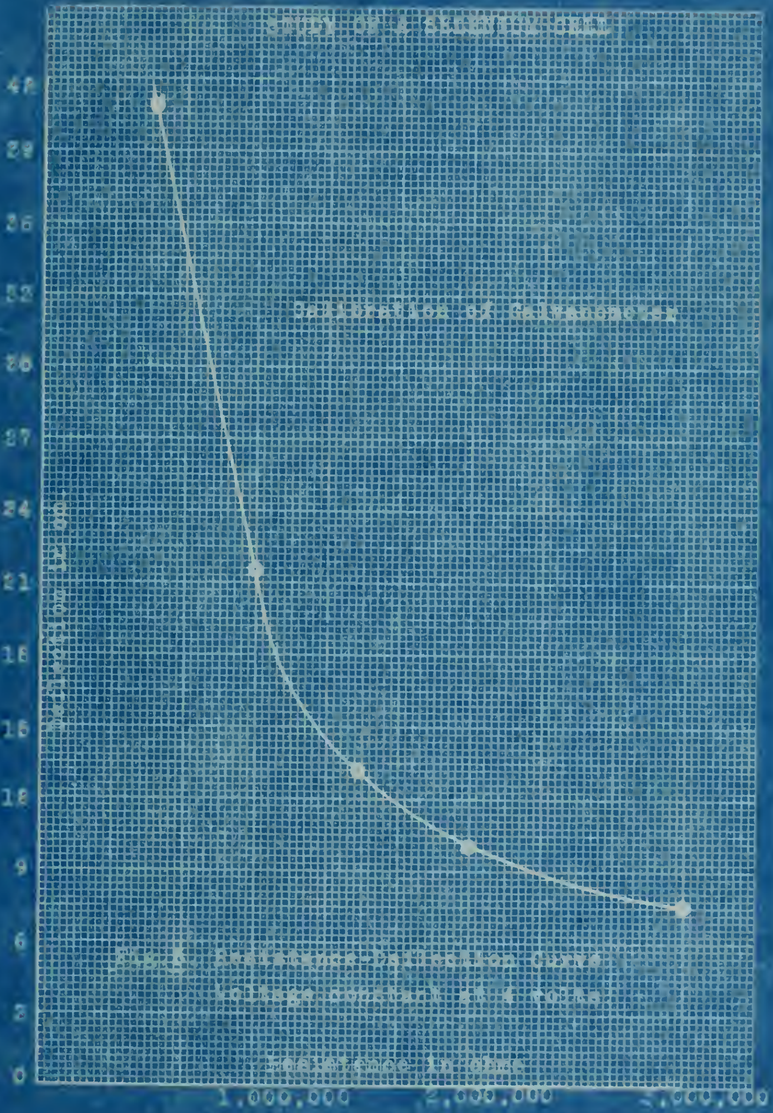

Fig. 4. Resistance Calibration Curve
Voltage constant at 4 volts

in the laboratory. The cover was suddenly withdrawn from the cell and it was exposed to the daylight illumination. Readings of the deflection of the galvanometer needle, on depressing the battery key, were taken at 10 second intervals. After the deflections had assumed a steady value, the cover was quickly replaced and readings taken for a recovery curve. (Curves shown in Fig.7)

Different illumination intensities ranging from 1 to 11 foot-candles (broad daylight) were obtained on different days in various parts of the laboratory and data accumulated for the illumination-resistance curve shown in Fig.8.

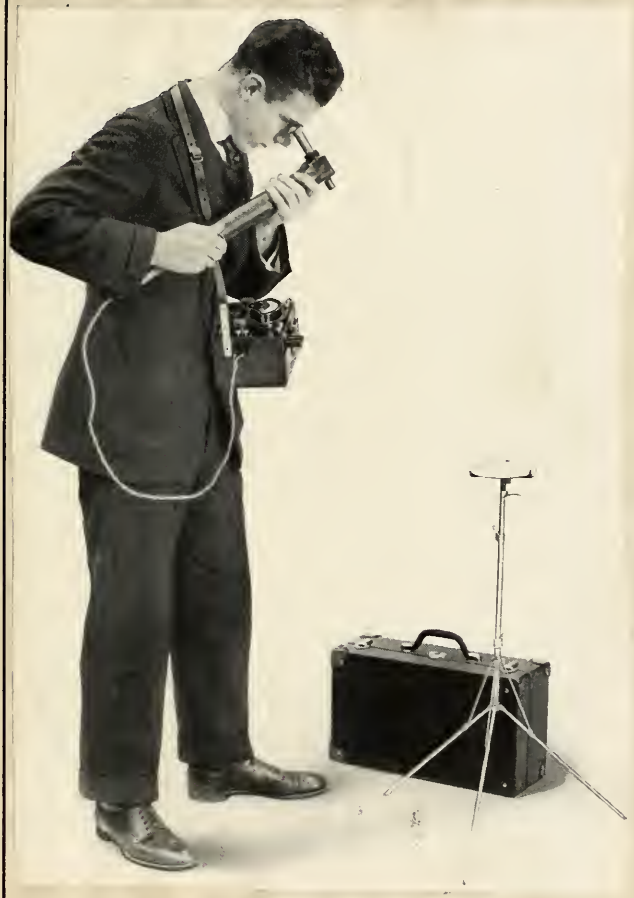

Fig.6. Macbeth Illuminometer In Use

(c) Experimental Data

Wheatstone Bridge measurement:

R_1 25,000 R_2 10,000 R_3 1,200,000

Dark resistance of cell, 3,000,000 ohms

Standard laboratory set- L & N # 126.

accuracy 1/50 %

Ratio 10,000 to 10 Reading 2999

Dark resistance of cell 2,999,000 ohms

Calibration of Galvanometer

Voltage	Resistance	Deflection
4	3,000,000 ohms	6.76 cm.
4	2,500,000	9.11
4	2,000,000	10.14
4	1,500,000	13.53
4	1,000,000	20.28
4	500,000	40.60
8	1,500,000	27.06
12	1,500,000	40.60

Illumination- Resistance Measurements:

Voltage constant at 4 volts.

Temperature of room 75° F.

Illumination constant at 10.5 f.c.

Deflection	Time	Resistance(cell)
6.76 cm	0 sec	3,000,000 ohms
7.00	10	2,897,100
12.00	20	1,690,000
14.00	30	1,448,500
16.00	40	1,267,500
18.00	50	1,126,600
19.60	60	1,035,000
20.20	70	1,000,000
20.28	80	1,000,000

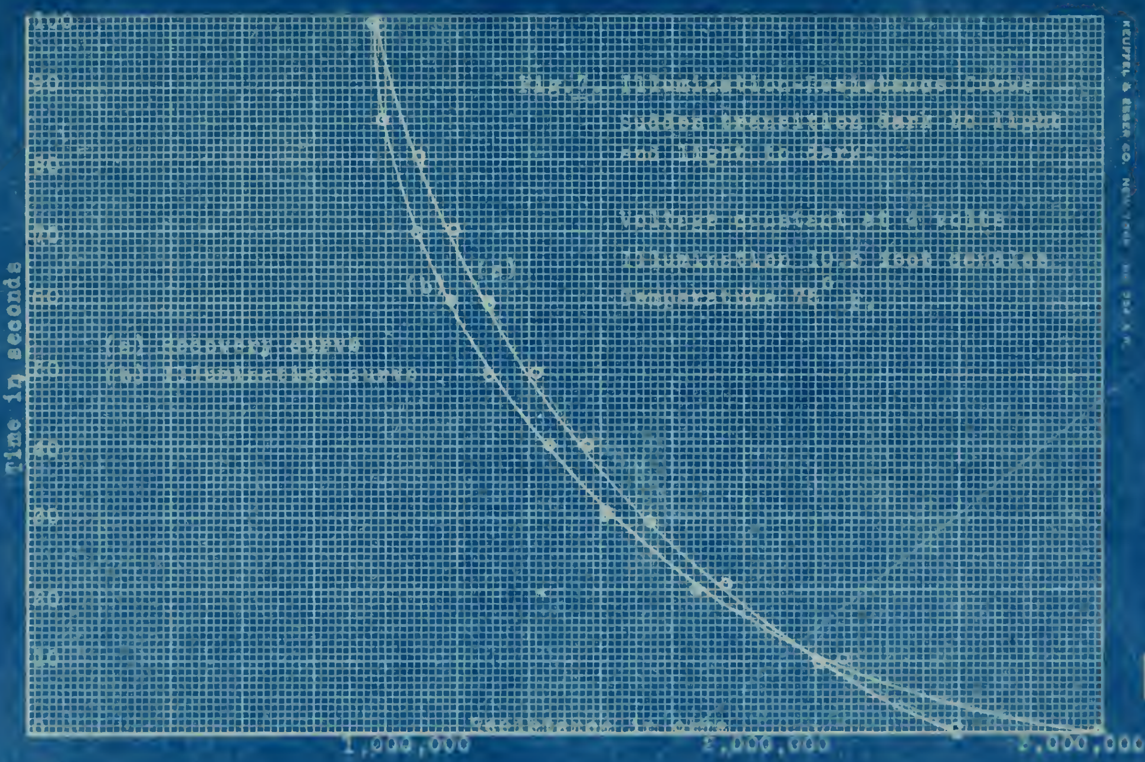

Fig. 7. Illumination-Resistance Curve
Sudden transition dark to light
and light to dark.

Voltage constant at 6 volts
Illumination 10.5 foot candles
Temperature 78° F.

Illumination- Resistance Measurements:

Voltage constant at 4 volts.

Temperature constant at 75° F.

Illumination (zero)

Recovery Curve- cell dark

Deflection	Time	Resistance
18.0 cm	90 sec	1,126,600 ohms
16.2	100	1,253,100
14.5	110	1,400,000
12.9	120	1,575,000
11.4	130	1,781,000
10.4	140	1,950,000
9.5	150	2,140,100
8.8	160	2,311,000
8.1	170	2,509,000
7.5	180	2,701,000
7.3	190	2,781,000
7.3	200	2,781,000

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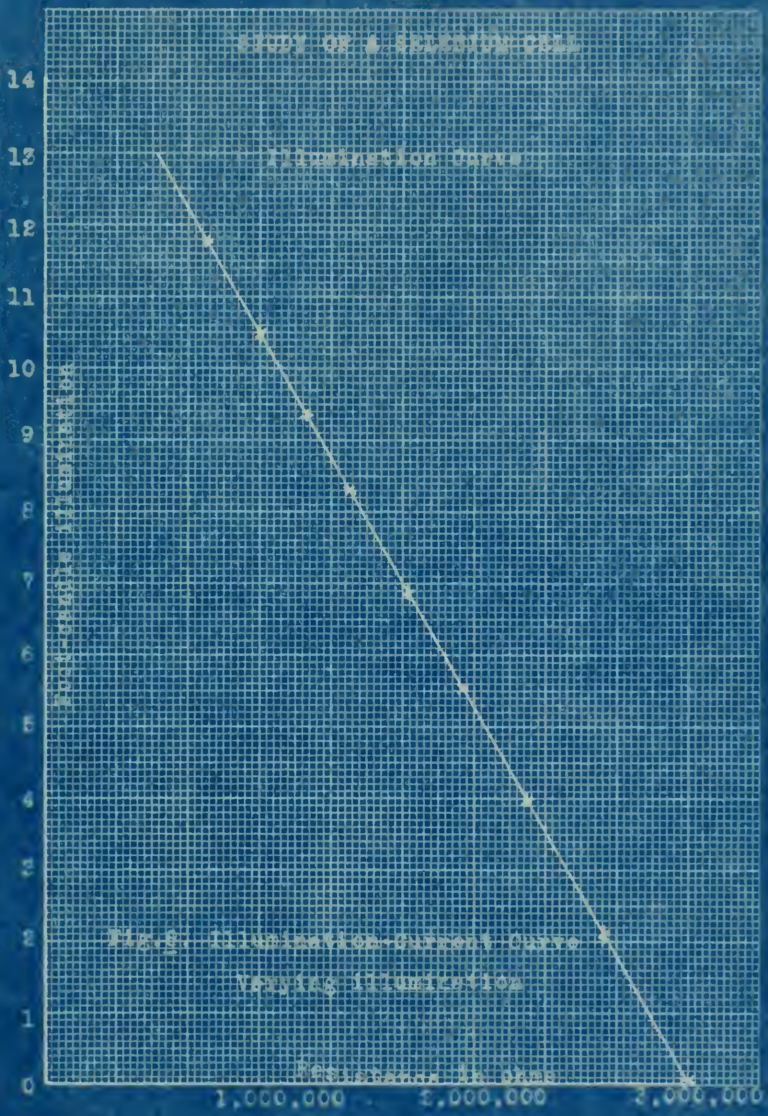

Fig. 8. Illumination-current Curve

Varying Illumination

Illumination- Current curve for varying illumination intensity.

Deflection	Illumination	Resistance
6.76 cm	0 f.c.	3,000,000 ohms
7.02	2.1	2,895,000
7.55	3.9	2,695,000
9.08	4.7	2,310,000
10.80	5.6	1,855,000
13.12	6.8	1,542,000
13.9	7.2	1,451,000
16.4	8.5	1,235,000
18.95	9.8	1,075,000
20.28	10.5	1,000,000
21.4	11.1	945,000

Discussion of Results.

The results obtained were surprising and somewhat disappointing. The cell was furnished by the makers with the statement that its change of resistance,dark to light, was 25 to 1, or a change of resistance from 300,000 to 12,000 ohms. The cell was either injured in some way or else did not live up to specifications.

As it stands, the linear relation between current and illumination was definitely proven between the limits and dark and daylight illumination. The range, however, is so small, that the use of this cell for the purposes intended, i.e., on lighting circuits, would involve the design of a galvanometer principle relay operating on low voltage; and it is doubtful whether it could be made accurate and sensitive enough to respond to small changes in illumination.

The work was carried out throughout with the idea of imposing conditions that would likely be met with in a modern office or building where the cell would be installed. The

resistance of the cell was measured at freezing outdoor temperature and the change of resistance was not large enough to warrant a temperature resistance curve.

A cell having a sensitivity of 25 or 30 to 1 would permit adjustments of non-operative and operative relays with a few percent leeway in each direction;a sensitiveness of 3 to 1 makes this impossible.

The linear illumination-current relationship being definitely proven leaves the problem one to modify or in some other way to secure a cell with the desired sensitivity, and then construct the mechanical features involved in snap and cut-out switches,for the operating conditions imposed on the cell. These problems the author hopes to work on in the near future.

APPENDIX

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